20.3: Novel Type of Bistable Reflective Display using Quick Response Liquid Powder

Reiji Hattori, Shuhei Yamada
Department of Electronics, Kyushu University, 6-10-1 Hakozaki, Higashi-ku, Fukuoka, Japan
Yoshitomo Masuda, Norio Nihei
Bridgestone Corporation, 3-1-1 Ogawahigashi-Cho, Kodaira-shi, Tokyo, Japan

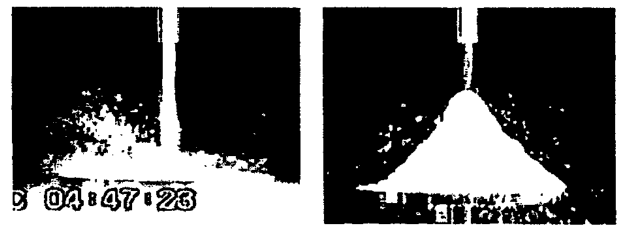
Abstract
We have developed new liquid-behavior-powder materials that realize a novel type of bistable reflective display showing paper-white appearance, high contrast and quick response. The demonstrated display has a 160×160 array of pixels and a 3.1-inch diagonal viewable image size with a pixel response less than 0.2 msec and is driven by passive-matrix addressing.

1. Introduction
Many types of bistable reflective displays have been demonstrated so far to target the mobile application market, but there is no display with both the characteristics of high-reflectivity and quick response.

The bistable LCDs[1,2] have a high contrast and a sufficiently fast-response time, but the reflectivity is never higher than 50 % theoretically (it's usually limited to about 30%) because of a polarizer. This low reflectance compels a poor legibility. On the other hand, the electrophoretic display[3] achieves a paper-white appearance but the pixel response is usually longer than 100 msec, which is not acceptable for moving images or comfortably fast scrolling even if it is driven by the active-matrix (AM) method. For bistable displays, the passive-matrix (PM) driving is the suitable and ideal driving method because of its hysteretic characteristics. Therefore the response of the cell is critical even to show the static image because the updating time is given by multiplying the response-time by the number of scanning lines. For example, the display with 400 scanning lines and a 100 msec pixel-response takes 40 seconds to show a static picture, which is a too long period to wait for a new picture.

"Paper-white" appearance is also an important factor for legibility. "Paper-white" does not mean only high-reflectivity but also ideal diffuse, or Lambertian, surface. Even though the display has a high-reflectivity and high-contrast, people will have an unpleasant feeling if it has an angular dependence of reflectivity[1,2] or angular color separation.[4] Therefore the ideal diffuse reflectance nature is absolutely needed to achieve an electronic paper.

We have developed new materials to achieve a bistable reflective display that can satisfy the requirements of high-reflectance and fast-response, simultaneously, and that has a paper-white appearance. The materials are in powder form showing the liquid behavior. We call the display "Quick-Response Liquid Powder Display" (QR-LPD®). Using these materials we demonstrated a prototype display that has a 160×160 array of pixels and a 3.1-inch diagonal viewable image size, driven by PM addressing. The demonstrated display was designed for PDA use, but this display has many kinds of applications, for example, as a large size POP, a display of RFID, an electronic book, an electronic news paper, a signboard, a traffic sign, a notice board, and so on. The biggest market of this display, we believe, is the one that is newly opened up by its special features, such as the ultra-low power consumption, low-cost of product productivity and the paper-like functionalities. Furthermore, we can easily utilize a plastic substrate for the QR-LPD® because it does not involve a high-temperature process. These materials and the simple structure have a tremendous ability to compete. We believe that the QR-LPD® is the best candidate to get a big market for the new electronic paper.



(a) (b)

Figure 1: The behavior of (a) the quick-response liquid-powder (this work) and (b) an ordinary powder.

2. Cell Structure and Performance
The materials we developed are two types of powders. One has white color and negative charge and the other has black color and positive charge. They are attracted to each other and make a mass with gray color, but each powder behaves just like a liquid by itself. Figure 1 shows the behavior of (a) the white and negative-charged powder developed in this work and (b) an ordinary powder with the same size. They are dropped onto a plane plate at the same rate. The ordinary powder piles up on the plate in a mountain shape, but the developed powder does not remain on the plate. This is an experiment to measurer the angle of repose, or to evaluate the liquidity of the powder material. Figure 1 (a) shows the extremely high liquidity of the developed powder, which allows the use of the term "Liquid Powder" for this material.

Figure 2 shows the architecture and the operation principle of the

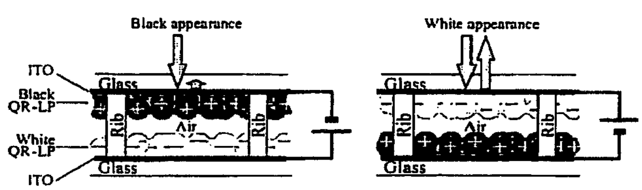


Figure 2: The QR-LPD® architecture and the operation principle

ISSN/0003-0966X/03/3402-0846-$1.00+.00

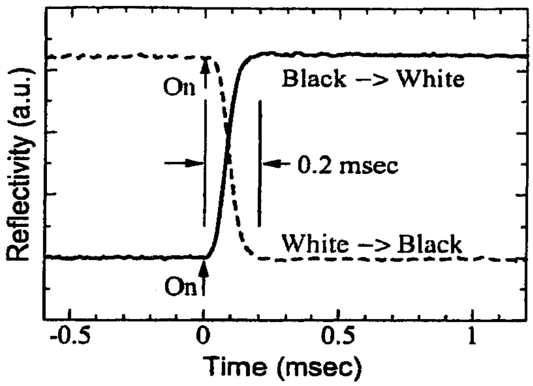


Figure 3: Response of reflectivity

QR-LPD®. An appropriate amount of both the white and the black powders is sandwiched by ITO-patterned glass plates separated by a distance of 50-100 μm. The rib keeps the cell gap and prevents mixing up of powders between the pixels. When a negative voltage is applied to the upper ITO electrode, the positively charged black powder moves to the upper electrode showing a black appearance (see the left figure in Fig.2) and in the opposite case the negatively charged white powder is attracted to the upper electrode showing the white appearance (see the right figure in Fig.2). These states are retained even if a voltage is not applied because of the induced image and Van der Waals forces.

At the early stage of this work, the applied voltage to move the powders was quite high, for example, several hundreds volts. The voltage, however, has been much improved to less than 100 V at present. This voltage level is still high for mobile use, but there is a good possibility to improve it further. On the other hand, the QR-LPD® cell has very sharp threshold characteristics, which mean that the PM driving method is suitable for the QR-LPD®.

Figure 3 shows the typical response curves of reflectance, where the solid line represents the response from the black state to white and the dashed line from white to black. The appropriate voltages were applied at the time of zero. The response time can roughly be estimated to be 0.2 msec for both the cases of turning white and turning black. Of course after turning off the applied voltage

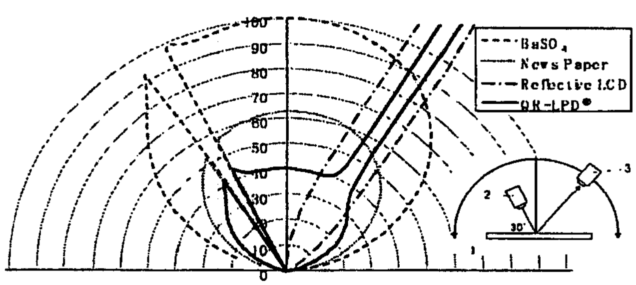


Figure 4: Angular dependence of reflectivity and the measurement set-up (1: Measured surface, 2: Collimated light source, 3: Detector).

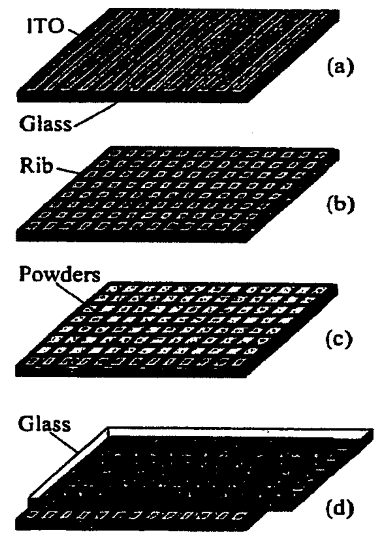


Figure 5: The fabrication process of the QR-LPD® panel. (a) The ITO electrodes are patterned on the glass substrate. (b) The rib was formed. (c) An appropriate amount of the powder is put into the pixel surrounded by the ribs. (d) The upper glass plate with patterned ITO electrodes is assembled on the lower plate.

the reflectivity keeps completely the same level. A change of reflectivity is not observed as long as no voltage higher than the threshold is applied. This quick response time allows updating fast and showing a moving image. We achieved an updating time of less than 67 msec with the demonstrated display (160 scanning lines). Though this updating speed is not fast enough to show a moving image on the 160 scanning line area, we can partially use the display for the moving image at 60 Hz on an area of less than 40 scanning lines. This is the unique function of a bistable display.

Figure 4 shows the results of angular dependence of the reflectivity and its measurement set-up. The sample surface was mounted on a stage, and illuminated by a collimated light source fixed at an angle of 30 degrees from the normal. The detector was moved changing the angle between -75 degrees and +85 degrees. We used the $BaSO_4$ surface as a perfect Lambertian diffuser reference. The surface of newspaper gives the ideal diffuse with a maximum reflectivity of 62 %. The demonstrated QR-LPD® also has a quite ideal diffuse reflectance except at the angle of right reflection which is due to the reflection from the glass surface. The maximum reflectivity is about 41% at the normal. For the LCD, the reflection is totally different from the Lambertian.

3. Display Structure and Performance

Figure 5 shows the fabrication process of the demonstrated QR-LPD® panel. A glass substrate was utilized in this panel, though it is not essential. A plastic substrate is also possible since the following process does not need a high temperature, which is a remarkable advantage, especially for a mobile display. The ITO was patterned to stripe shapes with 330μm width and 20μm space

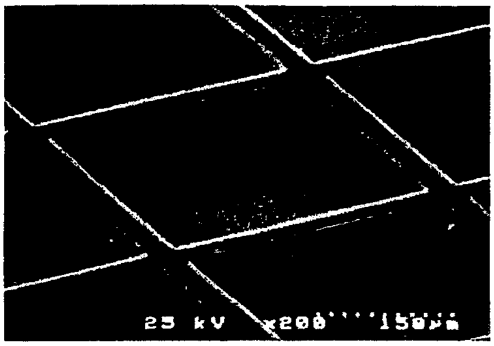


Figure 6: The rib structure on the lower plate.

(Fig. 5 (a)). The period of 350μm corresponds to the resolution of 66 dpi. This is not a limit of high resolution of the QR-LPD®. We have already succeeded in demonstrating a display with a resolution of 230 dpi. Then, a rib was formed to fix an electrode gap and to prevent uneven distribution of the powder between the pixels (Fig. 5 (b)). The ribs were located at the space between ITO electrodes. The height was varied from 50μm to 100μm, and the width corresponded to the electrodes space width, 20μm. Figure 6 is a picture of the rib structure. The square space surrounded by the rib makes a pixel. Then an appropriate amount of both the powders was put into the pixel (Fig 5 (c)). The upper glass plate with ITO electrodes patterned in the same shape as the lower plate is assembled on the lower plate (Fig. 5 (d)). The lower electrodes and the upper ones cross at right angle to each other.

This fabrication process is simple and inexpensive because of the simple structure and no TFT process in comparison with other displays, i.e. AM-LCD process. In addition, it does not need a high-temperature process. These are great advantages of the QR-LPD® over the LCD. Especially, the possible use of a plastic substrate is also a good advantage, because it results in a robust and flexible display. The gap-distance of QR-LPD® is expected to be insensitive in comparison with LCDs. The ideal diffuse reflectance nature also plays an important role in the case of a flexible display.

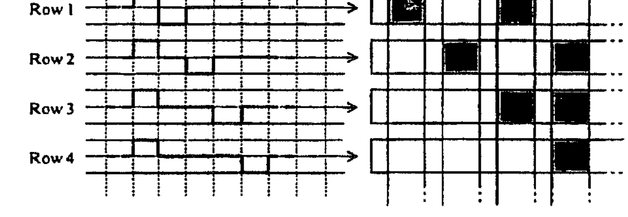


Figure 7: A basic driving scheme of QR-LPD®.

Figure 8: B/W image on prototype QR-LPD®.

Figure 7 shows a basic driving scheme of the QR-LPD®. At the beginning of showing an image on the display, all the pixels are erased by white (black) color by applying a certain high voltage to all the row-electrodes (column-electrodes) and a zero voltage to all the column-electrodes (row-electrodes). After that, row-electrodes are selected sequentially by applying the zero voltage and column-electrodes are selected by a high or zero voltage depending on the image data. Here we need to apply a medium voltage to the unselected row-electrodes so that a voltage higher than the threshold is not applied to the pixel cell. This medium voltage level is just half of the high voltage level and must be lower than the threshold voltage. This driving scheme is the simplest and the fastest one, but it is not suitable to show a moving image because the part where the row line is selected later is quickly refreshed and the time of showing the image is shorter than that of the first selected part. Therefore, the moving image has a gradation along to the scanning direction even if the scanning rate is fast enough. To prevent this effect, the erasing must be done line by line for the selected row-electrodes. In this case the moving image gets uniform but the frame rate gets slower. In addition, all-line erasing in the former driving scheme needs a higher current at erasing than in the line-by-line erasing in latter driving scheme. Therefore if we erase the image in the same period the driver IC needs to have a large capability to supply a high current, which causes a high load to the power source circuit, that is, a large size of the circuit. To avoid this, the all-line erasing time must be longer than the writing time.

Figures 8 is a photograph of the demonstrated QR-LPD®. The display has a 160×160 array of pixels, a 3.1-inch diagonal viewable image size and a 66 dpi resolution. The PM addressing as mentioned above was employed using custom IC drivers. The B/W image was written by all-line erasing method. The updating time of an image takes 67 msec including the erasing time. This time is comfortable enough for updating or scrolling an image.

Figure 9 shows a 4-gray-level image. If the high-voltage is reduced, black level gets imperfect and shows a gray level. The gray level can also be retained for as long a period as the black level and the gray level can be increased by the number of this writing sequence. Therefore the half-tone level is controlled by the number of writing of this image. The darkest pixel is written four times at a half-tone level. Therefore the time to show a half-tone image is four times longer than the B/W image in this method. There are many other ways to present a half-tone image besides this method, for example, the gray level can be controlled by the applied voltage or by the writing period. These methods need the same updating period but the uniformity of half-tone has not been confirmed.

4. Summary

The QR-LPD® offers a quick response of less than 0.2 msec, bright images with paper-white appearance and more than 42 % in reflectivity, infinite bistability, wide viewing angle with nearly ideal diffuse reflectance, large matrix addressing capability by PM driving and half-tone images with more than 4-gray-levels. The structure of QR-LPD® allows us to realize a simple and low-temperature fabrication process, which also means a flexible and high throughput display.

5. References

[1] E. L. Wood, P. J. Brett, G. P. Bryan-Brown, A. Graham, R. M. Amos, S. Beldon, E. Cubero, J. C. Jones, SID 02 Digest, p.22 (2002).

[2] C. Joubert, J. Angele, A. Boissier, P. Davi, I. Dozov, T. Elbhar, B. Pecout, D. Stoenescu, R. Vercelletto, SID 02 Digest, p.30 (2002).

[3] R. M. Webber,. SID 02 Digest, p.126 (2002).

[4] M. Miles, E. Larson, C. Chui, M. Kothari, B. Gally, J. Batey, SID 02 Digest, p.115 (2002).

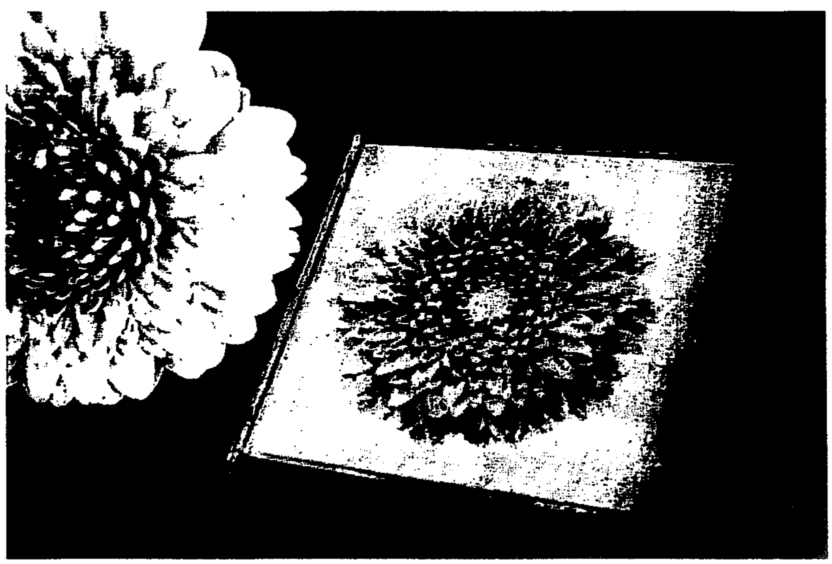


Figure 9: 4-gray-level image.